CHARACTERIZATION OF FRACTURE ZONATION USING SEISMIC DATA AND MCMC METHODS

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RESEARCH OBJECTIVES

Our goal in this study is to delineate fracture zonation in order to understand field-scale bioremediation experiments carried out at the DOE Field Research Center (FRC) in Oak Ridge, Tennessee, using crosswell seismic-travel-time and borehole-flowmeter-test data. Our focus is on the development of an effective joint inversion model for combining the crosswell geophysical data with the borehole measurements to characterize fracture zonation in high resolution. The joint inversion approach was developed to minimize problems sometimes encountered with sequential two-step hydrogeophysical estimation approaches, which entails initial inversion of the geophysical dataset, followed by the use of that dataset to estimate hydrogeological parameters. In this example, seismic anisotropy and discrepancies between the borehole and crosshole measurement support scales prohibited the meaningful use of the conventional two-step hydrogeophysical inversion approach for identifying the spatial distribution of fracture zones.

APPROACH

We developed a true joint inversion approach for estimating fracture zonation by combining crosswell seismic travel-time and borehole-flowmeter-test data using a Bayesian framework. First, we transferred the continuous values of hydraulic conductivity data, obtained from borehole flowmeter test data, into indicator values (1 = high conductivity, 0 = low conductivity), using the median of hydraulic conductivity as the cutoff value. Then, we created a Bayesian model to estimate the probability of being within the high-conductivity fracture zone at each pixel in space, by conditioning crosswell travel-time data and indicator values of borehole flowmeter test data. In the model, the prior probability of being within the high conductivity zone at each pixel was determined using an indicator kriging method. The likelihood function, which links seismic slowness (the inverse of seismic velocity) and hydraulic conductivity, was determined from cross-correlation analysis. Finally, we used Markov chain Monte Carlo methods (MCMC) to draw many samples of the indicator values at each pixel in space. Through statistical analysis of those samples, we obtained the probability of being within the high-conductivity fracture zone at each pixel.

ACCOMPLISHMENTS

Figure 1 illustrates the probability of being within the high-conductivity fracture zone along three vertical cross sections at the FRC site, obtained using the developed joint stochastic inversion approach. The cross sections illustrate the value of the developed procedure for such

investigations: in some cases, interpolation of borehole data might be sufficient for representing the connectivity of the fracture zone, while in other cases, such interpolation could lead to incorrect assumptions about fracture zone connectivity. Our fracture zonation estimates were corroborated using other types of information, such as field tracer breakthrough data and bioremediation results.
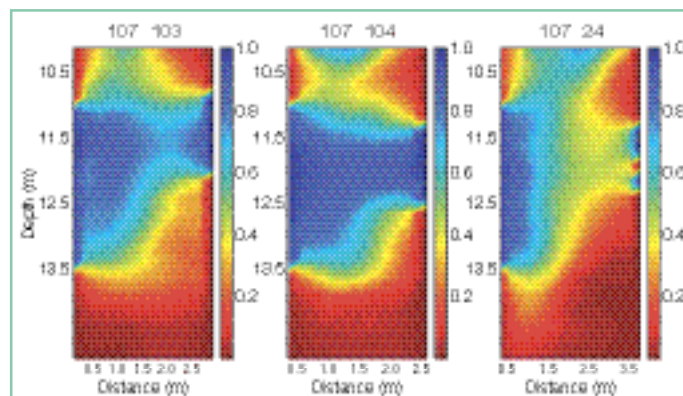

Figure 1. Estimated probability of being within the high-conductivity fracture zones along three transects at the DOE NABIR Field Research Center in Oak Ridge, Tennessee. The blue color represents high probability, the red color represents low probability.

SIGNIFICANCE OF FINDINGS

We have found that the developed stochastic MCMC model is effective for combining seismic travel-time and borehole-flowmeter-test data. This is one of the first examples of true joint inversion of geophysical and hydrological information for hydrogeologic investigations. The study also illustrates the value of using joint inversion methods for subsurface characterization, especially in "challenging" subsurface environments (such as the FRC), where conventional hydrogeophysical approaches fail to provide quantitative property estimates.

RELATED PUBLICATIONS

Chen, J., and S. Hubbard, Development of a joint hydrogeophysical inversion approach and application to a fractured aquifer. Water Resour. Res. (in preparation), 2005.

ACKNOWLEDGMENTS